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The Effect of Electrode Material on the Efficiency of Dielectric Barrier Discharge

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Abstract—The influence of the electrode material on the specific thrust of a synthetic jet based on the dielectric barrier discharge generated by a symmetric actuator has been studied taking into account the ionization energy and resistivity of the material. Dependences of the specific thrust on the distance between outer (exposed) electrodes made of copper, aluminum, and nickel are compared.

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The characteristics of synthetic jets generated by plasma actuators have been studied in a number of works, in which the variable factors included electrodynamic parameters (voltage applied to exposed electrodes, frequency) [1] and actuator configuration (spacing between exposed electrodes, dielectric-layer thickness, gap width between the exposed and encapsulated electrodes) [2, 3], while the material of electrodes has been given much less attention. The formation of a synthetic jet begins primarily with the release of electrons from the electrode surface [1], which implies that the ionization energy of atoms of the electrode material significantly influences the power of a jet emitted by the actuator. A significant role can also be played by the resistivity of electrode material [4], since it directly influences the efficiency of electric energy conversion into the kinetic energy of electrons and ions. In view of a low efficiency of the dielectric barrier discharge (~0.1% [5]), even a small increase in this value can lead to a significant increase in the energy of a synthetic jet created in this discharge.

The present work was aimed at studying the dependence of the specific thrust of a synthetic jet on the distance between external (exposed) electrodes of symmetric actuators with electrodes made of three materials possessing different resistivities and ionization energies. The values of these characteristics are presented in the table for copper, aluminum, and nickel. Copper and nickel have close ionization energies, but significantly different resistivities. The ionization energy of aluminum is 20% lower than that of copper and nickel. All electrodes had the same thickness (40 μm) and width (10 mm).

Figure 1a shows the scheme of a symmetric actuator, which comprised a 400-μm-thick fluoroplastic plate *1* onto which 40-μm-thick foil electrodes made of copper, aluminum, or nickel were glued. Upper (exposed) electrodes *2* had a width of 10 mm, while the width of the lower (encapsulated) electrode *3* was equal to gap width d between the upper electrodes. The exposed electrodes were connected by a high-voltage cable via a 900-Ω ballast resistor to a controlled source of high ac voltage with a frequency of 50 kHz. The encapsulated electrode was grounded.. The length of the discharge region along electrodes was within 12–14 cm.

Figure 1b presents a schematic diagram of the experimental setup used for measuring the specific thrust of a synthetic jet created by the symmetric actuator. According to this, actuator *4* was mounted on electronic balance *5* and connected by high-voltage wires *8* to high ac voltage source *6* via ballast resistor *7*. When the applied voltage amplitude was increased to 6 kV, a dielectric barrier discharge appeared in the space between exposed electrodes and created a synthetic jet that was manifested by increasing weight of the actuator. The specific thrust f of the synthetic jet created by the actuator was defined as the ratio of an increase in the actuator weight to the length of the discharge region measured along the electrodes:

$$f = \frac{F}{L}, \tag{1}$$

Parameters determining the effect of electrode material on the efficiency of dielectric barrier discharge

Material	Ionization energy, kJ/mol	Resistivity, nΩ m
Copper	745.5	16.8
Aluminum	577.5	28.2
Nickel	737.1	69.3

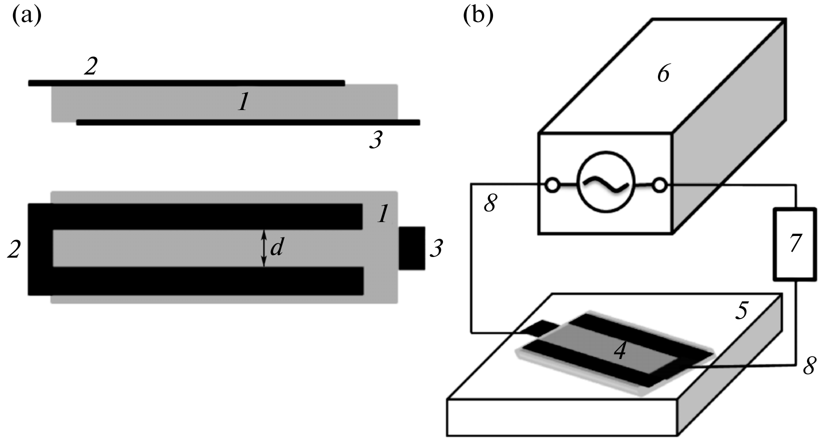

Fig. 1. Schematic diagram of (a) symmetric actuator and (b) experimental setup (see the text for explanations).

where F is the actuator weight increment due to the thrust developed by the synthetic jet and L is the length of discharge along the electrodes.

Figure 2 shows plots of specific thrust f of a synthetic jet produced by symmetric actuators with copper, aluminum, and nickel electrodes versus distance d between exposed electrodes for the applied ac voltage amplitude of 6 kV at a frequency of 50 kHz. The ionization energy for aluminum is significantly lower than that for copper, which results in the formation of a greater number of free electrons (for the same applied voltage) in the actuator with aluminum electrodes. This leads to a higher degree of air ionization and a greater volume force acting upon the flow and creating the synthetic jet. As a result, the specific thrust of the synthetic jet is about 15% greater for aluminum electrodes at all values of the distance between exposed electrodes. The values of specific thrust in the region of the extremum for nickel are greater than those for copper. Nickel possesses about a four times greater resistivity than copper at approximately the same ionization energy. Since the jets in our experiments were directed upward, convective flows introduced a positive contribution to the thrust developed by the synthetic jet and thus increased the efficiency of discharge—that is, the efficiency of conversion of the electric energy into kinetic energy of the synthetic jet. An increase in the distance between exposed electrodes leads to leveling of the specific thrust of actuators with copper and nickel electrodes. This is explained by the fact that an increase in the distance traveled by near-wall jets before collision leads to greater energy losses due to viscous forces and Joule heat fluxes from heated electrodes [6]. Thus, the positive effect observed under extremal conditions is counterbalanced by increased heat evolution from the surface of electrode.

Based on the established dependences, it can be concluded that a decrease in the ionization energy of the electrode material and an increase in its resistivity favor an increase in the specific thrust of a synthetic jet produced by a symmetric plasma actuator. The maximum effect is achieved as an extremum with respect to the applied voltage, frequency, and distance between exposed electrodes.

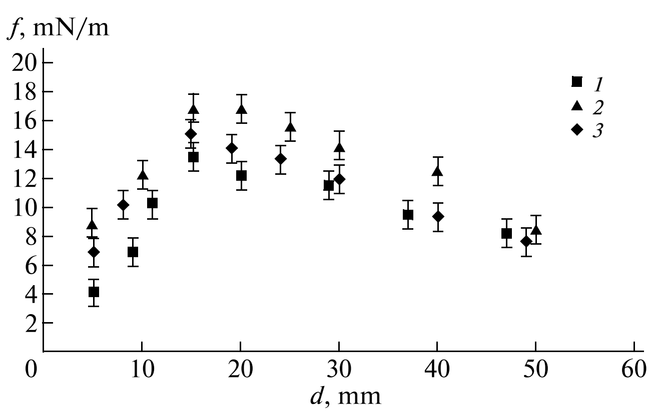

Fig. 2. Plots of specific thrust f of a synthetic jet produced by symmetric actuators with (*1*) copper, (*2*) aluminum, and (*3*) nickel electrodes vs. distance d between exposed electrodes.

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